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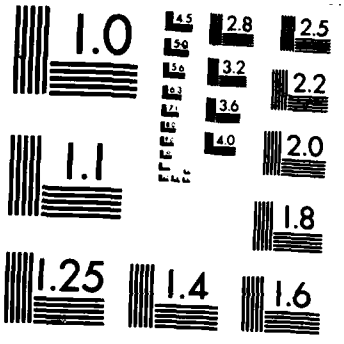

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THE UNIVERSITY OF ILLINOIS AT CHICAGO

FINAL SCIENTIFIC REPORT TO AIR
FORCE OFFICE OF SCIENTIFIC RESEARCH
Contract AFOSR 80-0170
DESIGN OF EXPERIMENTS AND RELIABILITY MODELS

Department of Mathematics, Statistics, and
Computer Science
University of Illinois at Chicago
Chicago, Illinois 60680

DEPARTMENT OF MATHEMATICS, STATISTICS, AND COMPUTER SCIENCE

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FINAL SCIENTIFIC REPORT TO AIR
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Contract AFOSR 80-0170
DESIGN OF EXPERIMENTS AND RELIABILITY MODELS

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Investigator in Design
of Experiments

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SUMMARY

In this report we list the scientific achievements and activities sponsored by U.S. Air Force Office of Scientific Research under contract AFOSR 80-0170 as of July 31, 1985.

I. INTRODUCTION

This is a final report of scientific achievements and activities sponsored by U.S. Air Force Office of Scientific Research under contract AFOSR 80-0170 as of July 31, 1985.

~~Our~~ research activities have been concentrated on two main areas: Design of experiments and Reliability.

~~Our~~ research on design of experiments relates directly to problems of data collection and analysis relevant to virtually all scientific experimentations. There is a strong need in the Air Force to reduce costs and save time in the collection and analysis of large amounts of data, such as communication, engineering, equipment testing, and aerospace medicine data. The reduction in costs and time should be done clearly without any damage to the statistical quality of the data being collected and analyzed. ~~Our~~ The research problems not only add to our store of knowledge about the multiple facets of data collection and data analysis in general, but ~~they~~ these have immediate applications to many important problems with which the United States Air Force is faced.

~~Our~~ main research emphasis has been to obtain designs which are efficient, easily applicable and yet meet the budgetary constraints. To reach the experimenters we have produced catalogs of such designs based on the many theoretical results which we have discovered. Some salient areas of our research are:

1. Repeated Measurements Designs:

These designs are very useful when experimental units are scarce and/or costly and thus have to be used repeatedly in experiments. Often the repeated use of the same un is essential, for example if one wants to measure the degree of adaptation of a human being to darkness over time. Human performance is an important factor in the safety of a system, but the

effect of human performance decreases by non weapons' effects such as fatigue and crew task overload. Repeated measurements designs allow for measuring and evaluating the residual effects as the results of fatigue, etc. We have identified and cataloged efficient designs which are easily applicable by practitioners. Our rigorous mathematical treatment of the problem has been recognized as a pioneering work in the area and has inspired many subsequent researchers.

2. Control Versus Treatment Designs:

Whenever an existing system is considered for replacement by one of several sophisticated or modern systems, the primary question is whether any of the new systems is truly superior in performance to justify the expenditure involved in the replacement. The existing system could be any equipment used in airplanes or on the ground, any office system like a computer or any drug, etc. The existing systems are the controls and the modern systems the rival treatments. In a series of publications we gave methods of obtaining optimal designs and developed catalogs of efficient designs for settings which are usually encountered in practice. We also identified several families of interesting optimal designs, some of which can be constructed by using well known geometrical structures. In addition we determined optimal designs which are robust against departures from the underlying assumptions.

3. Redesigning Experiments:

It happens quite often that a scientist proposes an elaborate experiment but discovers at a late stage that he has enough finances and/or time for a much smaller design. In modifying the original design the scientist has to take into account the fact that he may not be able to obtain observations at all the locations of his final design. Experiments are very often held

under hostile circumstances where it is most improbable that all the desired observations can be obtained. Thus the scientist will have to redesign his experiment based on the knowledge he has about which observations are most likely to be lost. We made specific recommendations on how to choose an experimental design smaller than the original one and yet sacrifice very little by way of reliability of the final results, or fulfilment of the principal objectives of the experiment.

4. Trade Off In Designs:

Sometimes it may happen that an efficient design may involve collecting observations at undesirable (for example, hostile, costly, inaccessible) locations. The trade off technique often remedies this difficulty by substituting these locations by more congenial ones without losing the essential statistical information needed for data analysis and modeling. We introduced this method and developed it further using sophisticated mathematical techniques.

The basic achievements of our research efforts in reliability have been mainly to introduce and develop useful models in the following important areas:

1. Degradable coherent systems which model situations in which both components and systems have several levels of performance ranging from perfect functioning to total failure. For such cases the existing binary models are gross oversimplifications. A rich theory for multistate coherent systems is essential to properly design, maintain and determine the "reliability" of such systems.

2. Multivariate models describing the joint random behavior of lifelengths (deterioration times) for n components which are not necessarily statistically independent. A proper understanding of such distributions

is essential in determining the reliabilities of systems formed from such components and the relative importance of such components within a system.

3. Optimal allocation of components in parallel-series and series-parallel systems, both in the binary and multistate cases. We have pioneered the use of the powerful techniques of majorization and Schur functions to successfully tackle various optimal allocation problems.

Our research efforts have been and continue to be very fruitful in yielding many useful and interesting results. This is demonstrated by the list of accomplishments detailed in the following section.

II. RESEARCH ACCOMPLISHMENTS

Our research activites during the past five years, since the inception of the grant AFOSR 80-0170, can be classified into four broad categories:

A. Production of forty-three research reports;

B. Production of two Ph.D. dissertations;

C. Production of an advanced book;

D. Presenting research results at scientific conferences held in the U.S. and abroad.

We shall now explain in some detail our effort in each of the four categories.

A. Production of forty-three scientific reports.

In this castegory we have produced forty-three scientific reports---the status of their publications in professional journals are as follows: Thirty of these reports are already in print, four reports have been accepted for publication, three reports are under consideration for publication, and the remaining reports are under revision for possible publication. These reports are:

1. Hedayat, A. and Khosrovshahi, G.B. An algebraic study of BIB designs: A complete solution for v=6 and k=3. J. Combinatorial Theory, Series A, 30, (1981), 43-52.

2. Constantine, G.M. Some E-optimal block designs. Ann. Statist. 9, (1981), 886-892.

3. Ash, A. Generalized Youden designs: Construction and tables. J. Statistical Planning and Inference 5, (1981) 1-25.

4. Hedayat, A. Study of optimality criteria in design of experiments. In: Statistics and Related Topics. (M. Csorgo, D.A. Dawson, J.N.K. Rao, A.K.Md.E. Saleh (eds.)) pp. 39-56 (1981). North Holland Publishing Co.

5. El-Neweihi, E. Stochastic ordering and a class of multivariate new better than used distributions. Comm. Statist. A 16 (1981), 1655-1672.

6. El-Neweihi, E. and Proschan, F. Unified treatment of some inequalities among ratios of means. Proc. Amer. Math. Soc. 91 (1981), 388-390.

7. Hedayat, A. Repeated measurements designs, IV: Recent advances. Bull. Int. Statist. Inst. (Proc. of the 43rd Session), XLIX (1981), 591-610.

8. Constantine, G. and Hedayat, A. A construction of repeated measurements designs with balance for residual effects. J. Statistical Planning and Inference 6 (1982), 153-164.

9. Constantine, G.M. On the E-optimality of PBIB designs with a small number of blocks. Ann. Statist. 10 (1982), 1027-1031.

10. Majumdar, D. and Notz, W. Optimal incomplete block designs for comparing treatments with a control. Ann. Statist. 11 (1983), 258-266.

11. Constantine, G.M. and Hedayat, A. Complete designs with blocks of maximal multiplicity. J. Statistical Planning and Inference, 7 (1983), 289-294. Corrigendum:Ibid: 7(1983), 417.

12. Hedayat, A. and Hwang, H.L. An algorithm for generating a basis of the trades on t-designs. Commun. Statist. Simula. and Computa. 12 (1983), 109-125.

13. Kageyama, S. and Hedayat, A. The family of t-designs: Part II. J. Statistical Planning and Inference, 7, (1983), 257-287.

14. El-Neweihi, E., Proschan, F. and Sethuraman, J. A multivariate new better than used class derived from a shock model. Oper. Res. 31 (1983), 177-183.

15. Hedayat, A. A characterization of a universally optimal design within a class of block designs. J. Statistical Planning and Inference, 9 (1984), 143-145.

16. Cheng, C.S., Constantine, G.M. and Hedayat, A. A unified method for constructing PBIB designs based on triangular and L_2 schemes. J. R. Statist. So. B, 46 (1984), 31-37.

17. Hedayat, A. and Hwang, H.L. BIB(8,56,21,3,6) and BIB(10,30,9,3,2) designs with repeated blocks. J. Combinatorial Theory, Series A, 36, (1984), 73-91.

18. Hedayat, A. and Hwang, H.L. Construction of BIB designs with various support sizes with special emphasis for v=8 and k=4. J. Combinatorial Theory Series A, 36, (1984) 163-173.

19. Federer, W.T., Hedayat, A. and Mendeli, J.P. Pairwise orthogonal F-rectangle designs. J. Statistical Planning and Inference, 10 (1984), 365-374.

20. Hedayat, A. and Majumdar, D. A-optimal incomplete block designs for control-test treatments comparisons. Technometrics, 26 (1984), 363-370.

21. Kageyama, S. and Tsuji, T. A condition for the validity of Fisher's Inequality. J. Japan Statist. Soc. 14 (1984), 85-88.

22. Hedayat, A. and Federer, W.T. Orthogonal F-rectangles for all even v. Calcutta Statistical Association Bulletin 33 (1984), 85-92.

23. Hedayat, A. and Majumdar, D. Redesigning experiments. In: Developments in Statistics and Its Applications, Proc. of the First Saudi Conference on Statistics and Its Applictions (1984), (A.M. Abouammoh, E. El-Neweihi, E. Aly, M.A. Alosh, eds.) 113-140. Published by the King Saud University Library, Riyadh, Saudi Arabia.

24. El-Neweihi, E. and Proschan, F. Degradable systems: A survey of multistate system theory. Comm. Statist. A13 (1984), 405-432.

25. El-Neweihi, E. Characterizations and closure under convolution of two classes of multivariate life distributions. Statist. Probab. Lett. 2 (1984), 333-335.

26. El-Neweihi, E. A class of multivariate new better than used processes. Proceedings of the First Saudi Symposium on Statistics and Its Applications, (1984), 509-519.

27. Hedayat, A. and Majumdar, D. Families of A-optimal block designs for comparing test treatments with a control. Ann. Statist. 13 (1985), 757-767.

28. Hedayat, A. and Majumdar, D. Combining experiments under Gauss-Markov models. J. Amer. Statist. Assoc. 80 (1985), 698-703.

29. Hedayat, A. and Pesotan, H. A study of BIB designs through support matrices. J. Statistical Planning and Inference 11 (1985), 363-372.

30. El-Neweihi, E. and Proschan, F. Component relevancy in multistate systems. Proceedings of the Sixth International Symposium on Multivariate Analysis. (1985), 203-208.

31. Hwang, H.L. On the family of (k,t) trades - useful tools for constructing t-designs from a given t-design. J. Statistical Planning and Inference (1986) in press.

32. Majumdar, D. Optimal designs for comparisons between two sets of treatments. J. Statistical Planning and Inference (1986), in press.

33. El-Neweihi, E. and Savits, T.H. Convolution of the IFRA scaled-mins class. Ann. of Probab. (1986) in press.

34. El-Neweihi, E., Proschan, F. and Sethuraman, J. Optimal allocation of components in parallel-series and series-parallel systems. J. Appl. Probab. (1986), in press.

35. Hedayat, A. and Lin, B.Y. Controlled probability proportional to size sampling designs. Bulletin of Institute of Math. Statist. 9 (1980), 282 (Abstract No. 80t-101).

36. Hedayat, A. and Lin, B.Y. A complete class theorem for probability proportional to size sampling designs. Bulletin of Institute of Math. Statist. 9 (1980), 297 (Abstract No. 80t-142).

37. Hwang, H.L A characterization of the trades on t-designs. Bulletin of Institute of Math. Statist. 12 (1983), 85 (Abstract No. 83t-21).

38. Hedayat, A. and Majumdar, D. Model robust optimal designs for comparing test treatments with a control, (1985) Statistical Laboratory Technical Report No. 85-4, Department of Mathematics, Statistics, and Computer Science, University of Illinois at Chicago.

39. Stufken, J. Optimal designs for comparing test treatments with a control. Bulletin of the Institute of Math. Statist. 14 (1985), (Abstract No. 85t-88).

40. Cheng, C.S., Majumdar, D., Stufken, J. and Ture, T.E. Optimal step type designs for comparing test treatments with a control. (1985) Technical Report, Department of Mathematics, Statistics, and Computer Science, University of Illinois at Chicago.

41. El-Neweihi, E., Proschan, F. and Sethuraman, J. Optimal allocation of multistate components. (1985) Technical Report No. 85-4, Department of Mathematics, Statistics, and Computer Science.

42. El-Neweihi, E., Proschan, F. and Sethuraman, J. Schur functions and the optimal assembly of coherent systems. (1985), in preparation.

43. Hedayat, A. and Pesotan, H. Characterization of triply balanced matrices with applications to survey sampling. (1985) Technical Report No. 84-5, Department of Mathematics, Statistics, and Computer Science, University of Illinois at Chicago.

B. Production of two Ph.D. dissertations.

Two research assistants have completed their Ph.D. dissertations under the direction of A. Hedayat.

These are:

1. Bing-Ying Lang Lin, "On probabilities proportional to size sampling designs: Their construction, algebraic properties and application", 1981.
2. Huey-Luen Hwang, "Trades and the construction of BIB designs with repeated blocks", 1982.

Another research assistant, John Stufken, started his research on Ph.D. dissertation in 1985 and is expected to finish his dissertation by 1986.

C. Production of an advanced book.

With the collaboration of W.T. Federer from Cornell University (United States) and Professor B.L. Raktoe from the University of Guelph (Canada),

we prepared an advanced book entitled Factorial Designs. This book appeared in 1981 in Wiley Series in Probability and Mathematical Statistics.

This book has been prepared with the following goals in mind: (i) providing the researchers with a complete and unified theory in the area of factorial experiments; and (ii) providing the practitioners with up-to-date applicable results in the area of multifactorial experiments.

Remarks: We are currently in the process of preparing two books tentatively titled:

(i) An introduction to the theory of optimal experiments.

(ii) An introduction to the theory and applications of survey sampling designs (co-authored with B.K. Sinha from Indian Statistical Institute).

D. Presenting research results at scientific conferences held in the U.S. and abroad.

As invited speakers we presented our newly discovered results at the following scientific meetings:

1. The 43rd session of the International Statistical Institute, Buenos Aires, Argentina, 1981.
2. The 181st meeting of the Institute of Mathematical Statistics, San Diego, California, 1982.
3. The Jack Kiefer and Jacob Wolfowitz Memorial Statistical Research Conference, Cornell University, New York, 1983.
4. The First Workshop on Efficient Data Collection, University of California, Berkeley, 1984.
5. The Fall Meeting of the Northeastern Illinois Chapter of the American Statistical Association, Northwestern University, Evanston, 1984.
6. The Second Workshop on Efficient Data Collection, University of California, Los Angeles, 1985.

7. The Sixth International Symposium on Multivariate Analysis, Pittsburgh, 1983.
8. The International Conference on Reliability and Quality Control, Columbia, Missouri, 1984.

We have also presented contributed papers at the following scientific meetings:

1. The 187th Meeting of the Institute of Mathematical Statistics, Orlando, Florida.
2. The 1985 Joint Statistical Meetings, Las Vegas.
3. The First Saudi Symposium on Statistics and Its Applications, Riyadh, Saudi Arabia.
4. The Air Force Office of Scientific Research Workshop on Reliability, Luray, Virginia, 1985.

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